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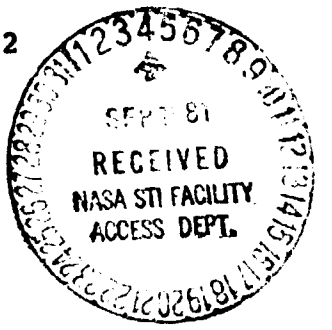
A MODULE EXPERIMENTAL PROCESS SYSTEM DEVELOPMENT UNIT (MEPSDU)

Quarterly Report No. 2

March 1, 1981 May 31, 1981

Contract No. 955902



SOLAREX CORPORATION

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The JPL Low-Cost Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initial a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DOE.

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ABSTRACT

The purpose of this program is to demonstrate the technical readiness of a cost-effective process sequence that has the potential for the production of flat plate photovoltaic modules which met the price goal in 1986 of 70¢ or less per Watt peak.

During the quarter, program efforts included:

- Preliminary Design Review
- Preliminary cell fabrication using the proposed process sequence
- Verification of sandblasting back cleanup
- Study of resist parameters
- Evaluation of pull-strength of the proposed metallization
- Measurement of contact resistance of Electroless Ni contacts
- Optimization of process parameter
- Design of the MEPSDU module
- Identification and testing of insulator tapes
- Development of a lamination process sequence
- Identification, discussions, demonstrations and visits with candidate equipment vendors
- Evaluation of proposals for tabbing and stringing machine

QUARTERLY REPORT

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FIGURES

1.0 Introduction

The purpose of the MEPSDU program is to demonstrate the technical readiness of a cost-effective process sequence that has the potential to produce flat-plate photovoltaic modules which meet the 1986 price goal of less than $.70 per peak Watt. To achieve this goal, Solarex will design, develop and fabricate a Module Experimental Process System Development Unit (MEPSDU) and will utilize the unit to produce a quantity of modules using the proposed process sequence. This effort will include:

- Design of a detailed cost effective process sequence,
- Completion of a detail design of the MEPSDU,
- Fabrication and assembly of the MEPSDU,
- Preparation of a process instruction manual, including in-line process control information,
- Performance of a minimum of three technical demonstrations which will include the production of sufficient modules and production data to permit validation of the contract goal,
- Performance of a cost analysis of the process sequence, including a study of the cost impact and changes required in the MEPSDU to allow the use of different types of input material.

In selecting a process sequence, we have emphasized the following considerations:

- Economics,
- State of verification,
- Availability of equipment for automation,
- Ease of integrating individual processes,
- Compatibility with the selected input material and a variety of other alternative silicon sheet materials.

In our design of the MEPSDU, we have chosen to develop a unit that is a forerunner of a production facility. This means that we will utilize production equipment, not laboratory-scale equipment. All manual handling of individual cells will be eliminated.

The concept of the MEPSDU is to demonstrate the process sequence and machinery by utilizing a single, rather than several parallel machines for each station. This means that the line itself is not a balanced production line, but all of the throughput rates are sufficient to demonstrate automated manufacture. Indeed, this unit itself will be capable of producing close to 10 MW per year with only minor modification (e.g. addition of several more laminating stations).

The baseline process sequence is described in Section 2.1. Any proposed changes in this baseline are described in Section 2.2. The detailed module design is given in Section 2.3.

Results of experiments performed in the second quarter are presented in Section 3. Section 4 summarizes our progress to date, including recommendations and conclusions, as well as presenting a brief schedule for the next quarter.

2.0 Process Description

2.1 Baseline Process Sequence

The baseline process sequence is shown in block form in Figure 1. This process sequence was described in detail in the First Quarterly Report (1). The baseline process sequence includes the following features:

- Semicrystalline silicon (10 cm x 10 cm) as the silicon input material;
- Spray-on dopant diffusion source;
- Al paste BSF formation;
- Spray-on AR coating;
- Electroless Ni plate-solder metallization;
- Laser scribe edges;
- Solder reflow tabbing and stringing machine; and
- Laminated EVA modules on glass superstrate.

2.2 Proposed Changes in Process Sequence

The use of a laser scriber as originally envisioned to provide an isolating trench around the cell is now under serious reevaluation. The standard negative screen printing techniques result in a halo of metal at the edges of the cell.

Figure 1

GENERAL PROCESS DESCRIPTION

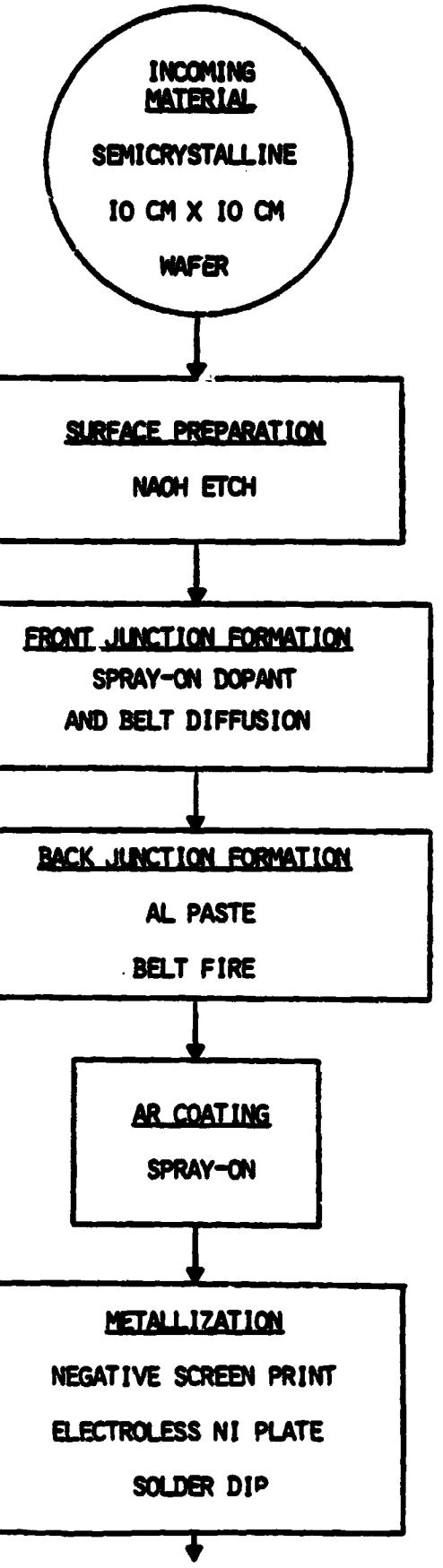
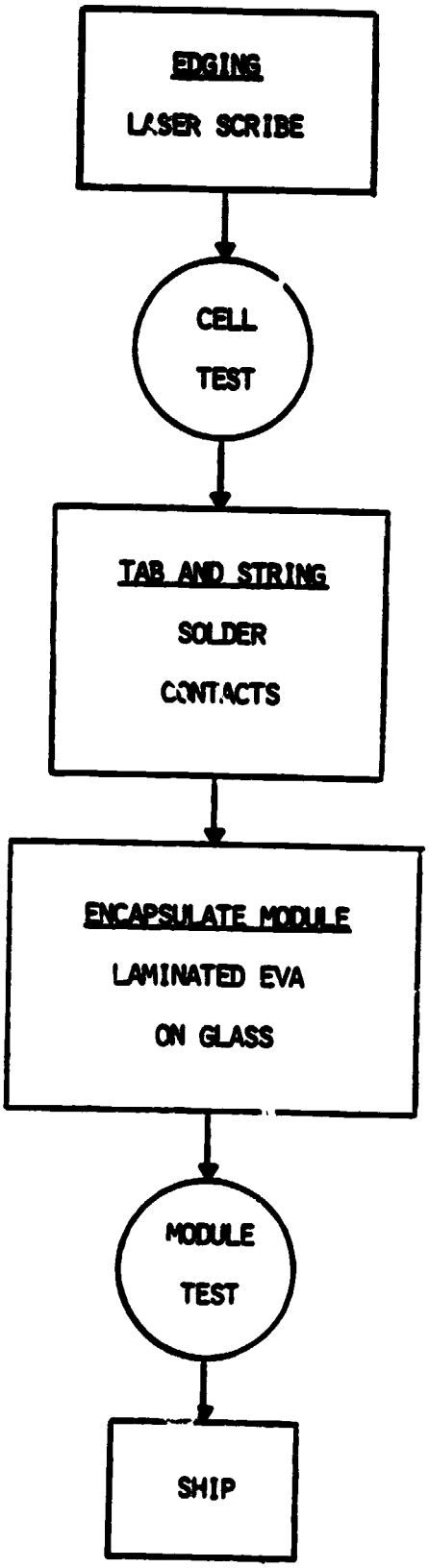


Figure 1 (cont'd)

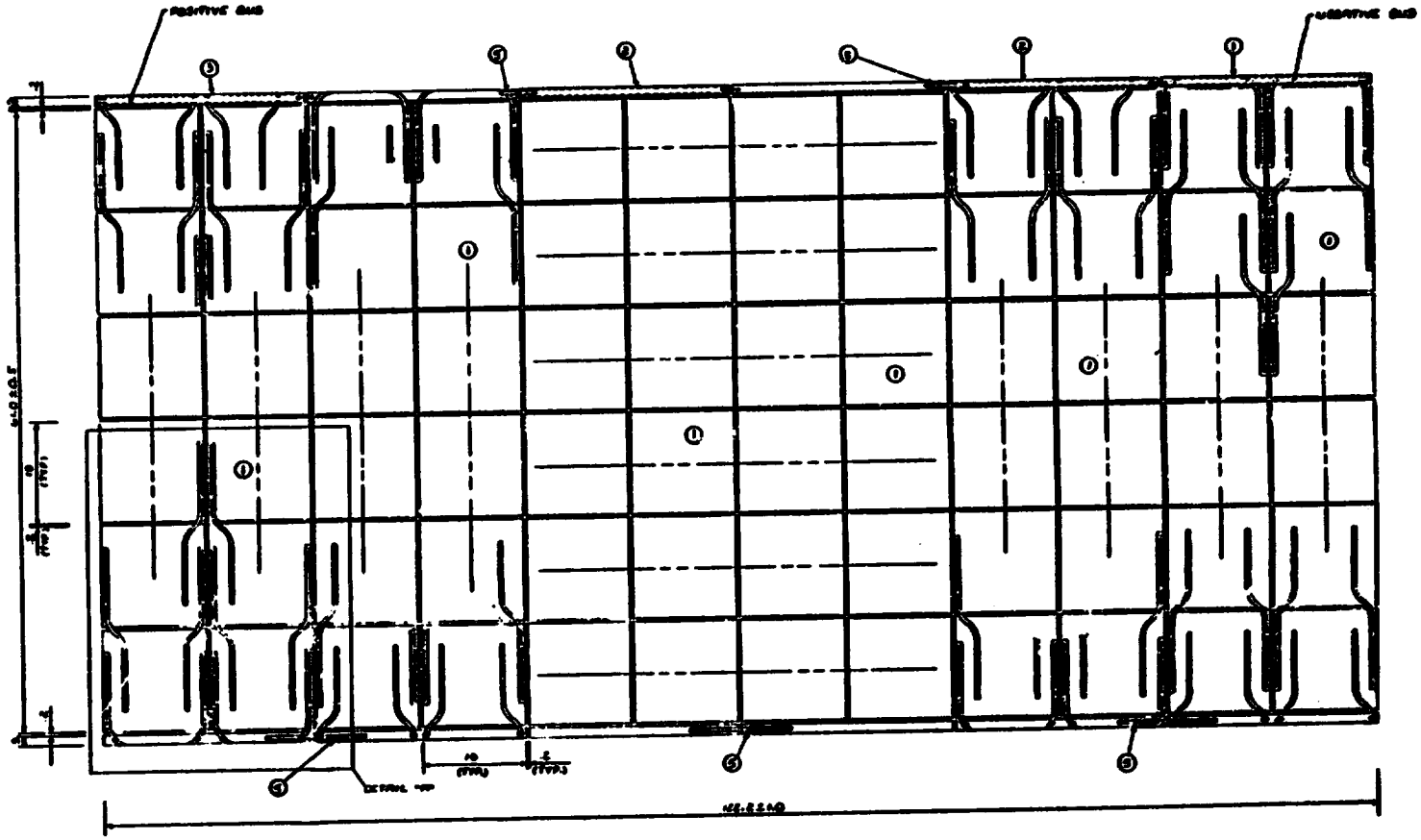


Laser scribing a halo on such a cell requires that the scribe line always be inside of the halo, resulting in significant loss of active cell area. In addition, there is a high likelihood that the front (n^+) interconnect can come in contact with this metallized halo. This would result in shorting of the cell, since this halo is electrically connected to the p^+ back of the cell. Four alternative approaches to laser scribing have been identified and are under evaluation. These approaches are described in Section 3.7.

2.3 Module Design

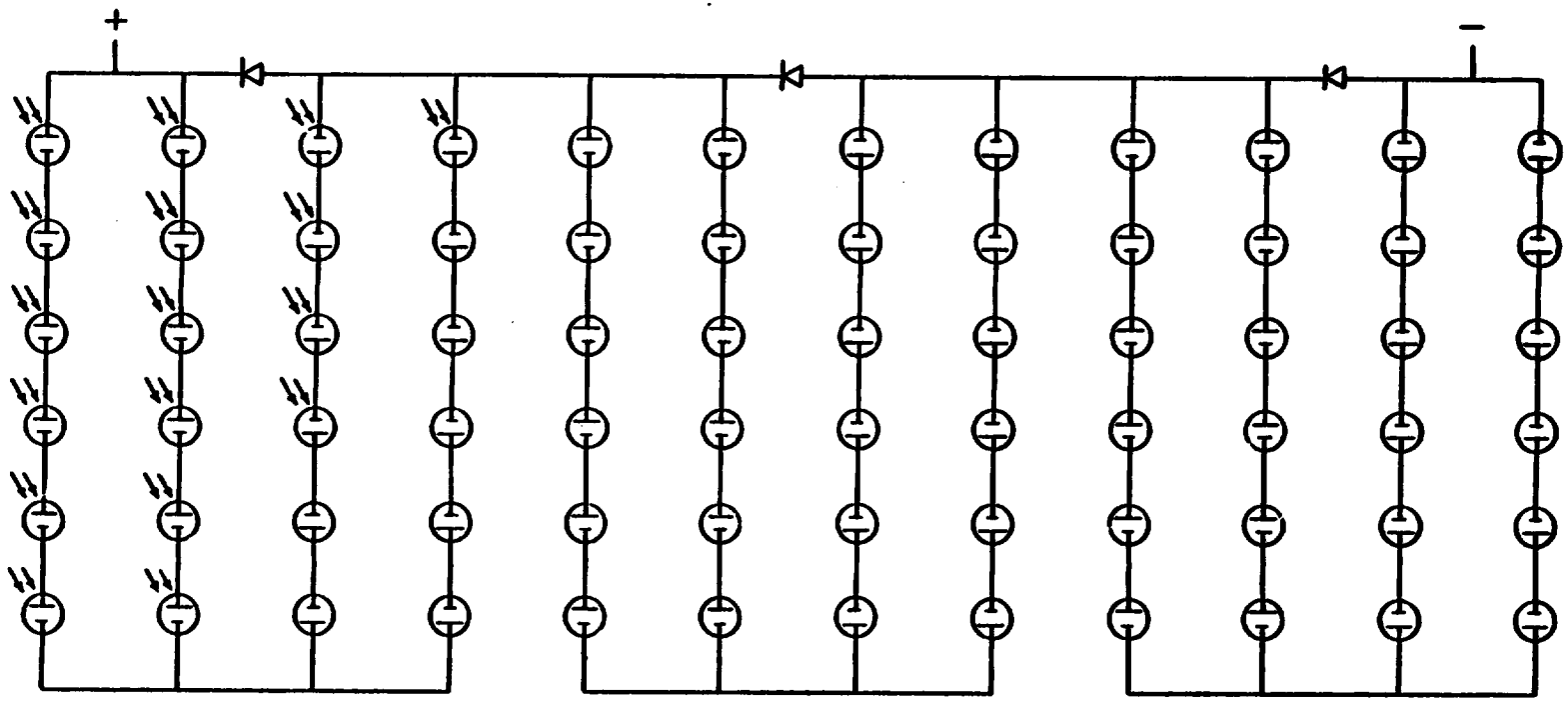
The basic module design has remained the same, utilizing seventy-two 10 cm x 10 cm semicrystalline cells with an electrical hookup of two cells in parallel with 36 series blocks. However, several problems with the proposed module layout, mainly associated with the placement of the long diode wire and the paralleling cross-straps, led us to reconsider the design. Rather than series stringing 12 cells along the four foot dimension of the module, we will now series string six cells along the two foot dimension as shown in Figure 2. The diode tabs now span the short region between bus bars and paralleling is provided by the bus bars. The electrical layout of the module is shown in Figure 3.

During the preliminary design review, concern was expressed as to our choice of 1/8 inch annealed glass. Because of the



MEPSDU CELL ASSEMBLY

FIGURE 2



MEPSDU ELECTRICAL SCHEMATIC

FIGURE 3

probable mechanical problems associated with this glass, we have reevaluated the selection and are now using 1/8 inch tempered glass as our baseline, but will continue to investigate the possibility of utilizing lower cost glass.

A revised drawing package is now in preparation to reflect these changes.

3.0 Technical Progress

3.1 Documentation

The following technical documentation was submitted during this quarter:

Item	
7.	Quarterly Report No. 1
8.	Technical Progress Report No. 4
9.	Technical Progress Report No. 5
10.	Technical Progress Report No. 6
11.	Revised Program Plan

3.2 Surface Preparation

The problems associated with NaOH vapors, splatter and boil-over, have been discussed with several vendors. Preliminary designs and quotes are being prepared.

3.3 Front Junction Formation

Spraying experiments at both Solarex, using a hand held air brush, and at Advanced Concepts, using an automated machine, were conducted. Emulsitone Phosphorofilm for solar cells was utilized as the dopant in each case. These experiments are described below:

(1) Single and semicrystalline wafers were sprayed at Advanced Concepts using a variety of spraying conditions as described in the First Quarterly Report (1). The wafers were diffused at

910°C for ten minutes with oxygen flow. Standard space cell processing was performed using Ti/Pd/Ag metallization and evaporated TiO_x Ar coating to produce 2 cm x 2 cm cells. The results are given below as measured at AM1 and 25°C.

	Power (mw)	Eff. (%)	I_{sc} (mA)	V_{oc} (mV)	FF (%)
Semicrystalline (Avg. of 85 cells)	49	12.25	114	574	75
Single Crystal Control (Avg. of 10 cells)	63	15.75	136	596	78

The use of a spray nozzle with a larger opening resulted in a more difficult oxide removal, but equivalent electrical performance.

(2) Semicrystalline wafers were sprayed manually with Phosphorofilm, then diffused in exygen. Two wafers each were diffused at 910, 900, 890, 880, and 870°C. The oxide was stripped in 20:1 HF with a slight amount of unremovable residue remaining (<1%). Sheet resistivity was measured in three places across the wafer.

Temp (°C)	Sheet Resistivity	Avg
910	42, 30, 31 28, 30, 32	32 Ω/□
900	32, 42, 42 34, 35, 41	38 Ω/□
890	43, 36, 40 37, 45, 47	41 Ω/□
880	57, 52, 60	56 Ω/□
870	77, 68, 67 71, 59, 93	72 Ω/□

These were made into 2 cm x 2 cm cells using standard space metallization (TiPdAg), but without AR coating. The results are summarized below at AM1 and 25°C.

Temp.(°C)	P_{sh}	P_{max}(mW)	I_{sc}(mA)	V_{oc}(mV)	FF	% Eff
870°C	72 Ω/□	40.4 mW	97 mA	564 mV	.738	10.1 %
880°C	56 Ω/□	41.3 mW	98 mA	566 mV	.745	10.3 %
890°C	41 Ω/□	38.2 mW	95 mA	558 mV	.721	9.5 %
900°C	38 Ω/□	39.4 mW	96 mA	562 mV	.730	9.8 %
910°C	32 Ω/□	34.0 mW	89 mA	552 mV	.692	8.5 %

(3) Lot 10

Thirty semicrystalline 10 cm x 10 cm wafers were etched and hand-sprayed with Emulsitone phosphorofilm according to the preliminary MEPSDU process sequence. Three categories of cells were prepared:

Lot 10A: Four wafers were belt diffused at 910°C for twelve minutes. The diffusion oxide was very pale. Metallization was TiPdAg. No AR coatings were applied. The wafers were cut into 2 cm x 2 cm cells. The results are summarized below at AM1 and 25°C.

Pmax	=	26.8	mW
Isc	=	80	mA
Voc	=	552	mV
Eff	=	8	%
Yield	=	87	%

Lot 10B: Six wafers were diffused at 910°C for ten minutes in a quartz diffusion tube. Metallization was TiPdAg. No AR coatings were applied. The wafers were cut into 2 cm x 2 cm cells. The results are summarized below.

Pmax	=	31.6	mW
Isc	=	86	mA
Voc	=	551	mV
Eff	=	7.9	%
Yield	=	92	%

Lot 10C: Twenty wafers were coprocessed through belt diffusion with Lot 10A. The wafers were then processed into 10 cm x 10 cm cells using the MEPSDU process sequence. The results are summarized below.

Pmax		430	mW
Isc		1.46	A
Voc	=	539	mV
Eff	=	4.3	%
Yield	=	32	%

(4) This experiment was designed to evaluate diffusion in a belt versus diffusion in a tube. Both single and semicrystalline silicon were used with identical standard TiPdAg processing, except for the diffusion drive-in step. No AR coatings were used. The two groups are described below.

Lot 11A: Wafers were tube diffused at 910°C in oxygen for ten minutes. The results on 2 cm x 2 cm cells are described below.

	Semicrystalline	Single Crystal
Pmax	34.7 mW	39.2 mW
Voc	547 mV	556 mV
Isc	90 mA	101 mA
FF	0.705	0.7
Eff (AM1-25°C)	8.7 %	9.8 %
No. of Cells	90	42

Lot 11B: Wafers were belt diffused at 910°C in air for twelve minutes. The results on 2 cm x 2 cm cells are described below, with no AR coating.

	Semicrystalline	Single Crystal
Pmax	30.2 mW	35.6 mW
Voc	535 mV	548 mV
Isc	78 mA	87 mA
FF	0.724	0.742
Eff (AM1-25°C)	7.55 %	8.9 %
No. of Cells	90	47

In this experiment, the single crystal cells were more efficient than the semicrystalline, and the tube diffused cells were better than belt diffused. Work is now in progress to optimize the processing of semicrystalline silicon with special emphasis on the belt diffusion parameters.

During one experiment, the Emulsitone Phosphorofilm failed to wet the cells. It appears that the dopant depolymerized. Filtration or addition of surfactants did not improve the wetting. It appears that the dopant has a limited shelf life of about four months.

3.4 Back Junction Formation

Tests were conducted to determine the optimum screening parameters for the Al paste. We used Engelhard Paste, 3 inch Cz wafers (1-2 Ω-cm), a diffusion process that resulted in a

80 - 120 Ω/□ diffused region, a standard TiPdAg metallization, an 850°C alloy temperature, and ≥ 20 second alloy time. All other screening parameters except the screen size were held constant, including an 80 mil snap-off point and a medium screen speed. The results are given below.

Screen Size	80	100	150	200	250 (1 mil)	250 (0.5 mil)
I_{sc} (mA)	112	115	114	113	110	
V_{oc} (mV)	481	592	589	579	492	
P (mW)	30.5	52.1	48.9	40.4	29.6	Eractic Results
FF	0.5	0.77	0.73	0.62	0.49	
No of Cells	17	14	23	13	16	
Paste Thickness (microns)	60-70	65-70	40	20.25	30	30.35

We repeated this experiment, but included one lot that used an 80 mesh screen with a longer (30 second) alloy time. The results are given below:

Screen Size	80	80	100	150
Alloy Time (seconds)	20	30	20	20
I_{sc} (mA)	117	117	118	115
V_{oc} (mV)	596	597	597	593
P(mW)	52.4	55.0	54.2	53.7
FF	0.75	0.79	0.77	0.79
No. of Cells	24	24	47	28

These results indicate that a mesh with larger openings produces higher voltage and that, for these thicker pastes, longer alloy times are required.

3.5 Back Cleanup

Back cleanup efforts have been directed in two areas:

(1) HCl Etch Cleanup

Experiments were conducted using an FSI 2120 Etch-Strip machine. The machine performed well, was easy to program with sequences of operations, allowed easy process optimization, and possessed several safety features which prevented operator access to the sample chamber when acid was being sprayed. Based on results obtained on lots of three to six cells, the 2120 E/S could produce 150 visibly clean and dry 10 cm x 10 cm cells in a best time of 13.5 minutes. This time did not include an initial warm up period or the time to load and unload cassettes. Sequential steps of HCl etch, rinse, HF etch, rinse, and dry were carried out and the rinse times out to the minimum that still showed acid neutralization. The detailed process sequence and machine settings for the optimized Al-alloy etch are indicated below.

Process		Time (sec)	RPM	Atomizing Pressure (lb/m^2)	
Full Strength	HCl etch (60°C)	300	10	16	
	DI Rinse (cold)	180	10	28	
100:1	HF etch (60°C)	60	10	16	
	DI Rinse (cold)	120	10	28	
	Spin dry (90°C)	150	999	72	(w/blanket heater)

Total time 810 sec = 13.5 minutes

Flow rates for all processes were 1-2 liters/min.

Best throughput = $\frac{150 \text{ wafers}}{13.5 \text{ min}}$ = 11.1 wafers/min.

IR transmission tests indicated that even a five minute spin cleanup in HCl was not sufficient to remove all of the residues. After recleaning the wafers in hot DI water in an ultrasonic bath, the R+T curve increased by two to three percent, showing that after etch the samples were too dirty to make adequate solar cells.

During these experiments, it was discovered that the HCl degraded rapidly, probably because of the decreased HCl solubility at the 60°C temperature used. This presented two problems: (a) Much fresh HCl must be added for each batch of cells, probably two liters/150 cells, and most of the used HCl dumped. This frustrates the recirculation feature of the machine; and (b) Since so much warm fluid is dumped, there is essentially an initial heat up delay of 20 minutes each time a batch of cells is run, drastically lowering throughput.

An attempt will be made to use lower temperature HCl in order to increase the lifetime of the etchant. It is probable that this will slow down the etch rate, resulting in longer process times.

(2) Glass Bead Cleanup

In preliminary experiments, wafers were alloyed in a belt furnace and others alloyed in a tube at 850°C for 25 seconds. Backs were cleaned by "glass beading" and were then treated for one minute in HF vapor, one minute in 0.1 N HCl and a quick dip in distilled water. They were immediately plated for seven minutes in Halma nickel solution at 85°C, pH about 8.5, then rinsed in water and dried.

Six tabs were soldered to each back and pull strengths were determined:

Back	Belt Furnace Alloy	Tube Alloy
Pull Strength (g)		
High	1332	1928
Low	198	283
Mean	532	875
Std. Dev.	364	510

These are quite acceptable results and they suggest that good pull strengths are obtained when you achieve a reproducibly good glass bead cleanup.

In a second tab pull experiment, the backs were glass beaded using new sandblast equipment (Dayton Model 3Z619).

Five four inch diameter round wafers were processed on a cell production line through the alloy step. Backs were cleaned by beading, requiring well under one minute for each wafer. Wafers were plated using our MEPSDU process (one minute HF vapor, one minute 0.1 N HCl, ten seconds distilled water, seven minutes in Halma electroless nickel bath at 85°C, pH about 8.5).

A total of 29 tabs were soldered to the backs of the five wafers and 90° pull strength measurements were made with the following results:

High	992 g (35.0 oz)
Low	326 g (11.5 oz)
Mean	625 g (22.0 oz)
S.D.	162 g (5.7 oz)

These are quite good pull strengths and quite consistent results for pull strength measurements.

Thirteen cells were fabricated with glass bead cleanup on the backs. The cells were four inch diameter round ones processed on a cell production line through the Al paste screening step. The Al was fired in the laboratory tube furnace. The back was cleaned using glass beads. The MEPSDU process was used for masking, etching, and plating.

The back was then masked with Kapton tape, leaving a small open section near one edge and a single strip about 3/16 inch wide across the back. Cells were then solder dipped and IV curves taken (AM1, 25°C).

Open circuit voltages ranged from 0.575 to 0.595 volt (mean 0.591). Short circuit currents ranged from 2.0 to 2.1 amperes. Maximum power ranged from 0.60 to 0.80 watt (mean 0.72). The best cell had an efficiency of just about ten percent.

A second lot of four inch single crystal cells was fabricated using the glass bead cleanup. The performance is summarized below:

Voc	=	597 mV	
Isc	=	0.222 Amp	
Pmax	=	0.883 W	(at AM1 and 25°C)
Eff	=	10.9 %	
FF	=	0.67 %	

The bead-back cleaned cells had higher overall performance than the control cells with HCl back cleanup.

3.6 AR Coating

A series of experiments were performed to determine if a pretreatment of the wafer would significantly improve the uniformity of the AR coating. Three experiments were conducted.

(1) Wafers were coated with 2-ethyl-1-hexanol and then sprayed as usual. The wafers had to be baked for three minutes to dry. There were lines of thick deposits of TiO_x due to uneven evaporation of the binders.

(2) Both butanol and n-Butyl Acetate were coated on the wafers. Both partially evaporated away before the AR mixture could be sprayed on the wafer, resulting in an uneven coating.

(3) A variety of solvents were sprayed, including 2-ethyl-1-hexanol, butanol and n-Butyl Acetate. The latter two evaporated almost immediately while the results with 2-ethyl-1-hexanol were the same as in (1) above.

We will try to identify and use a material that has a boiling point around 150°C so that it will be more volatile than 2-ethyl-1-hexanol, but less volatile than butanol.

3.7 Metallization

The following sets of metallization experiments were conducted.

(1) The first set consisted of experiments on four sets of wafers. Wafers were diffused, cleaned in 20:1 HF, rinsed in DI water, and dried. Wafers were then screen printed with Colonial Resist Ink No. ER-6055 and baked six minutes at 120°C. The first two sets (Nos. 1 and 2) were left overnight at this stage and were given an additional three minute bake at 120°C the next day.

Sets 1 and 3 were treated for five minutes in 1:1 (24 percent) HF while Sets 2 and 4 were treated for three minutes in HF vapor from 70 percent HF. All four sets next received two three-minute rinses in distilled water and were then immediately plated for seven minutes in Halma electroless nickel solution at 85°C, pH about 8.5.

Resist ink was removed by two consecutive thirty minute ultrasonic baths in trichloroethylene followed by rinses in 2-propanol and distilled water. The wafers were then dipped in solder and tabs were soldered to their pads (two on each wafer). Results of tab pull tests:

Set	1	2	3	4
No. of Tabs	26	23	22	24
Pull Strengths (g):				
High	1077	1276	1446	1361
Low	57	28	113	340
Mean	437	429	571	703
Std. Dev.	233	310	315	274

These results indicate that the Colonial ink can be screen printed and exposed to the AR etch reagents with minimum contamination of the areas to be plated, although the presence of low pull strengths indicates probable lack of complete removal of the resist.

(2) In the second set of experiments, six wafers (four inch round Cz) were processed on a cell production line through the back alloy step. They received a spray-on AR coating and were then screen printed (Colonial ink) and baked for six minutes at 120°C. Cells were etched one minute in HF vapor (from 70 percent HF), plated for seven minutes in Halma nickel solution at 85°C, pH about 8.5, rinsed in water and dried.

Ink was removed by a one hour ultrasonic bath in trichloroethylene. Cells were next rinsed in 2-propanol and dried, then solder dipped. Two tabs were soldered to each cell and pull strengths were determined:

High	624 g
Low	0 g
Mean	411 g
Std. Dev.	216 g

Ten of the twelve tabs showed good pull strengths. The weakness is probably in the removal of the resist ink (a single trichloroethylene bath was used) and a quicker, cleaner removal process is needed.

(3) We have been having trouble achieving a rapid cleaning of resist ink from cells when using cassettes in a small laboratory ultrasonic cleaning bath.

We conducted experiments using three different solvents in the same ultrasonic bath, but without using cassettes. All

three solvents (methylene chloride, trichloroethylene and 1,1,2-trichloroethane) produced good cleaning in seven minutes, with no obvious difference among the three.

Experiments were also conducted with trichloroethylene in a more powerful ultrasonic bath (Blackstone model HT-1.9). Using a single cassette, cells were cleaned completely in two minutes. Using two cassettes at one time lengthened the required time to seven minutes.

The plastic cassettes obviously absorb a lot of the ultrasonic energy, but adequate ultrasonic baths are available.

3.8 Electroless Ni Contact Resistance Measurements

The basic idea in making contact resistance measurements is to separate out the contribution of the metal contact from the semiconductor being contacted. This is done by depositing a series of metal contacts on a wafer, measuring the resistance of a series of contacts with increasing separation, and extrapolating to zero separation to find the contact resistance. Two geometries of Ni contacts have been tried and are shown in Figures 4 and 5. The analytical expressions for these cases are given below:

Case a: $$R_t = 2R_c + \frac{\rho}{\pi t} \ln (r/D-1)$$

Case b: $$R_t = 2R_c + \frac{\rho}{lt} r$$

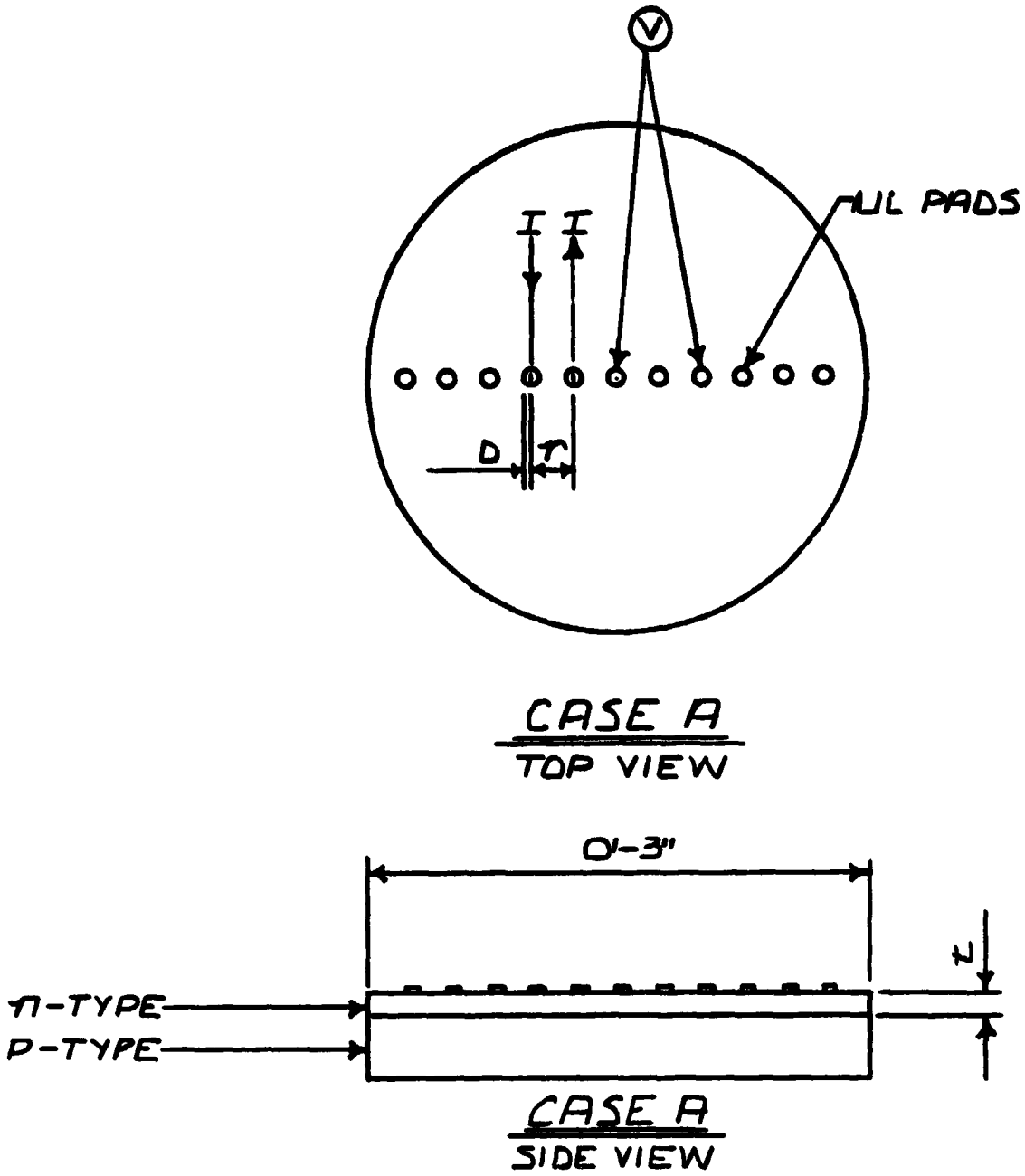
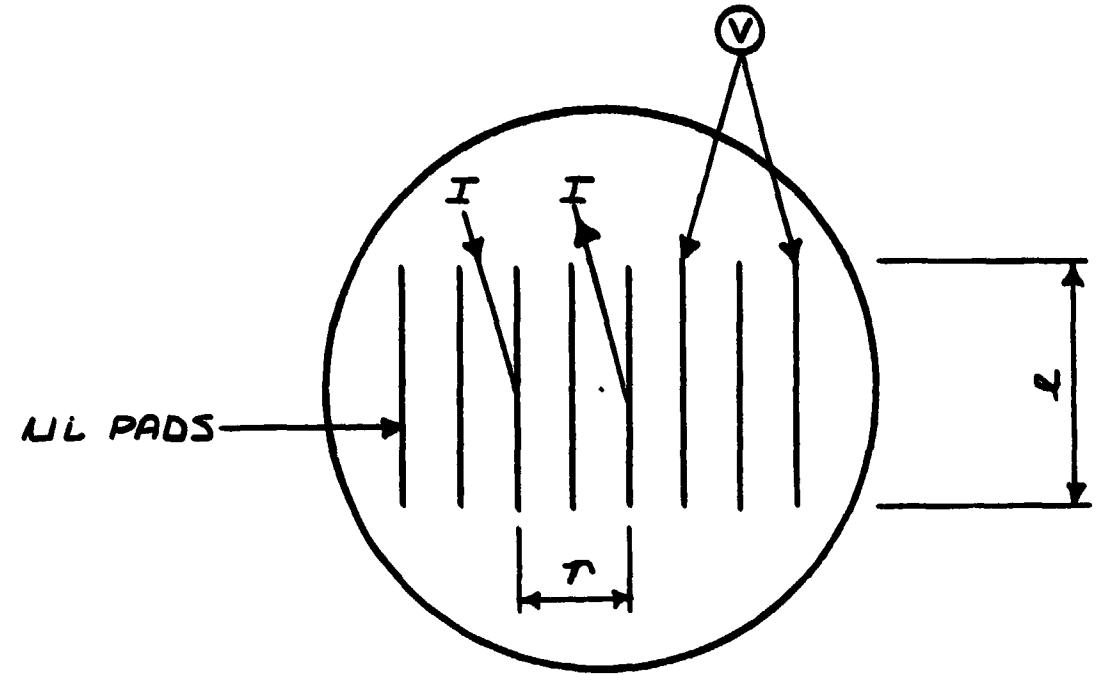
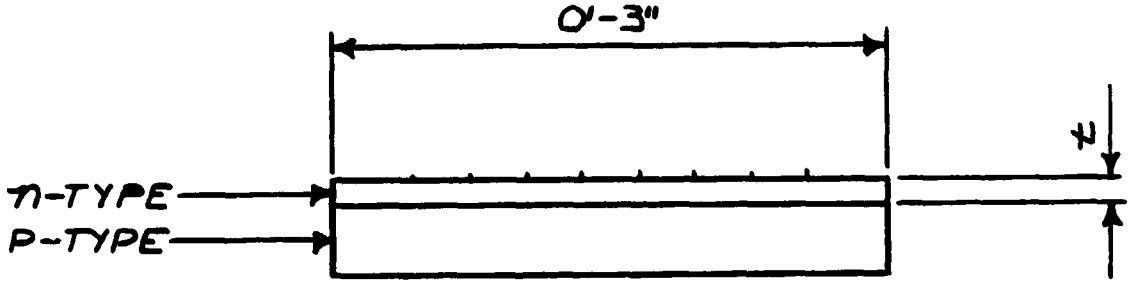


FIG. 4 CASE A GEOMETRY FOR CONTACT RESISTANCE MEASUREMENTS



CASE B
TOP VIEW



CASE B
SIDE VIEW

FIG. 5 CASE B GEOMETRY FOR CONTACT RESISTANCE MEASUREMENTS

In both cases plots of R_t, the total resistance, vs the appropriate variable gives a straight line plot with intercept yielding R_c, the Ni contact resistance, and slope yielding ρ/t, the sheet resistance.

Several samples were prepared with both circular and linear contacts. Starting wafers were p-type, 1-2 ohm-cm resistivity. They were subjected to an NaOH etch, an n-type diffusion to a sheet resistance of 36-38 ohm/sq, an HF etch, and a seven minute electroless Ni deposition through a kapton tape mask. Resistance measurements on Ni stripes indicate a Ni thickness of roughly .3 μ. In all cases, the Ni pads were contacted by soldering tabs directly to the Ni. Consistent measurement required cleaning the flux off solder joints with isopropyl alcohol. Ni pads as small as 0.20 cm in diameter can be soldered also, but with difficulty, and the entire Ni pad often pulls free of the Si in the course of measurements for the 0.20 cm pad size.

The soldered Ni contacts were tested for ohmic behavior by measuring V vs i from 0 to 120 ma and by measuring the current flow through the contacts. No appreciable rectification effects were seen from current reversal and i vs. V remained linear up to 60 ma. At 60 ma heating effects were presumbably occuring so that measuring currents should be kept below 60 ma and in practice generally ran 5-10 ma.

Since contact resistances were small, 4 wire techniques were used to avoid measuring the resistance of lead in wires.

In addition to contact resistance measurements, sheet resistance measurements were made with the four point probe to check the variability across the wafer and to compare to the values obtained from the contact resistance measurements.

Figures 6 through 8 show R_t vs contact separation. Circular and linear contacts generally show good agreement with theory yielding $R_t \alpha \ln(r/D - 1)$ and $R_t \alpha r$ respectively. Edge effects were noticeable in all cases and were minimized by staying at least 2 cm from the wafer edges. R_c was found to decrease with increasing Ni area but only the circular contacts seem to have roughly equal R_cA products. In addition the sheet resistance determined from the contact resistance measurements was generally lower than that measured with the 4 point probe, presumably because the contacts were not points. Results are summarized below:

Sample	ρ/t from slope ($\Omega/\square$)	ρ/t by 4 pt probe ($\Omega/\square$)	R_c (Ω)	Area (cm^2)	R_c area (Ω-cm^2)
2 mm diam.	39 ± 8	37.7	$6 \pm 4\Omega$	.036 ± .01	.22 ± .2
4 mm diam.	29 ± 8	36.7	$3 \pm \frac{1.2}{0.5}$	.12 ± .02	.36 ± .2
1 mm. linear	28 ± 8	36.7	$2 \pm \frac{1}{0.3}$	.93 ± .1	1.9 ± 1

FIGURE 6 RESISTANCE VS. CONTACT SEPARATION

.40CM. DIAMETER CONTACTS

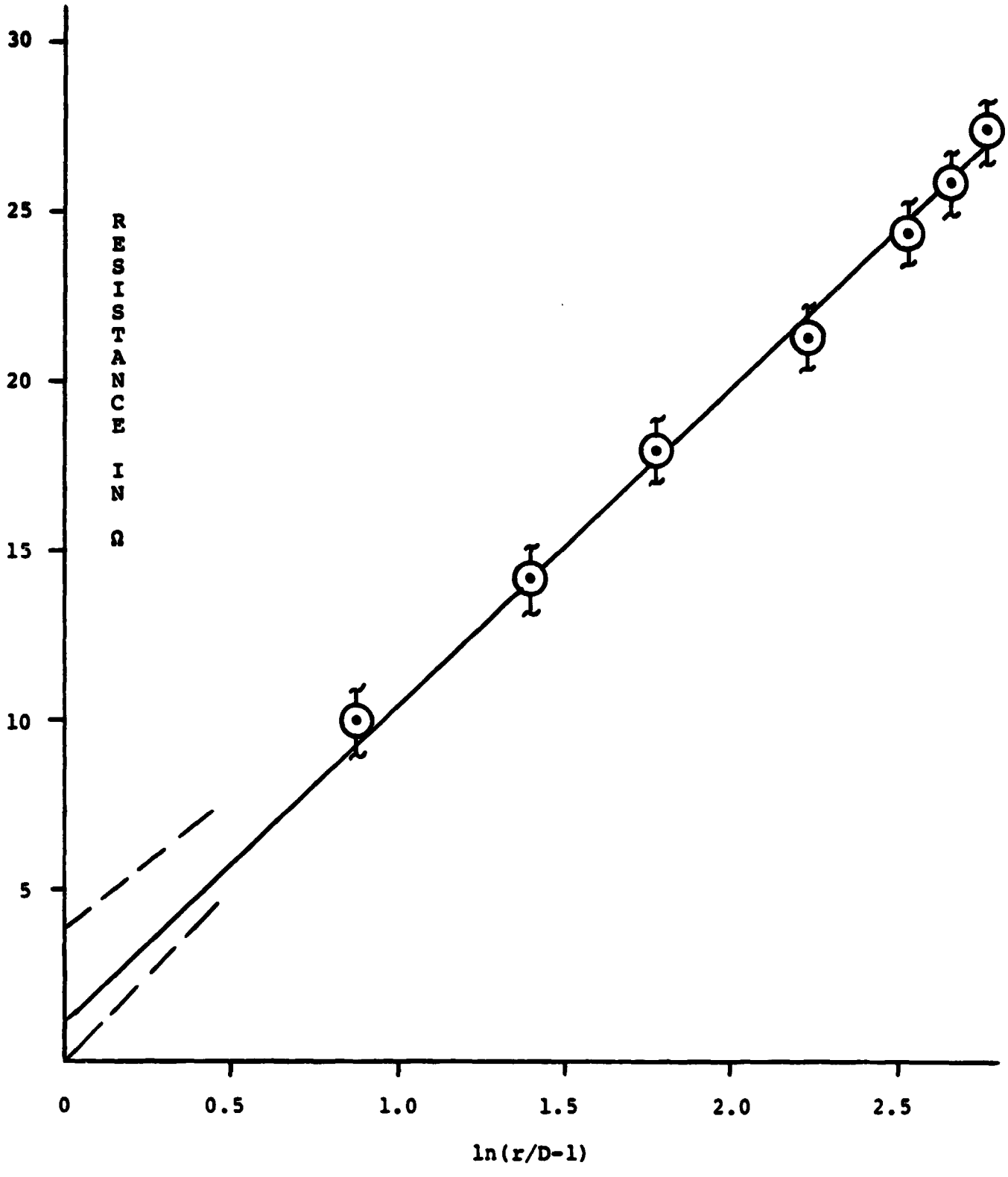


FIGURE 7 RESISTANCE VS. CONTACT SEPARATION

LINEAR CONTACTS

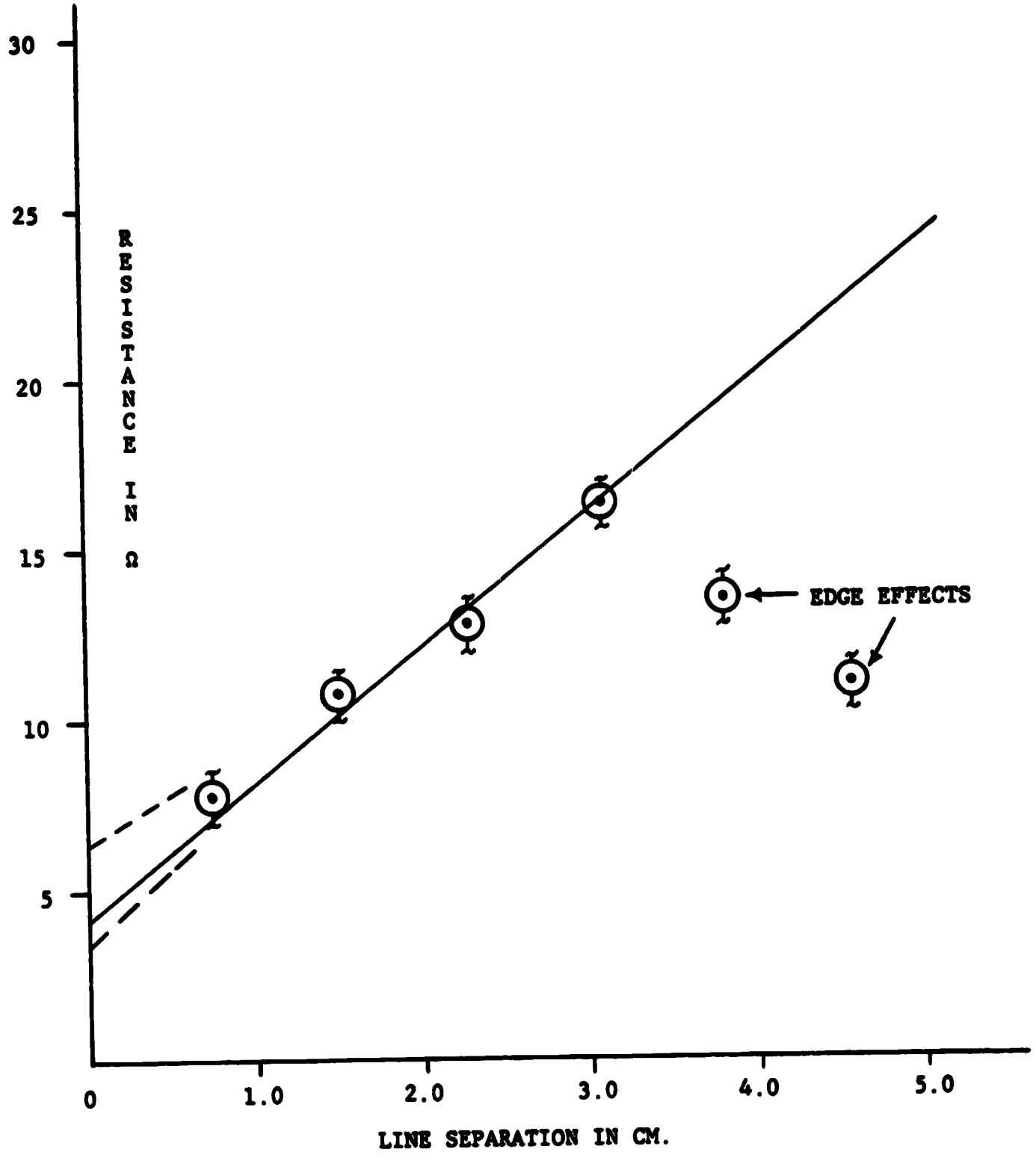
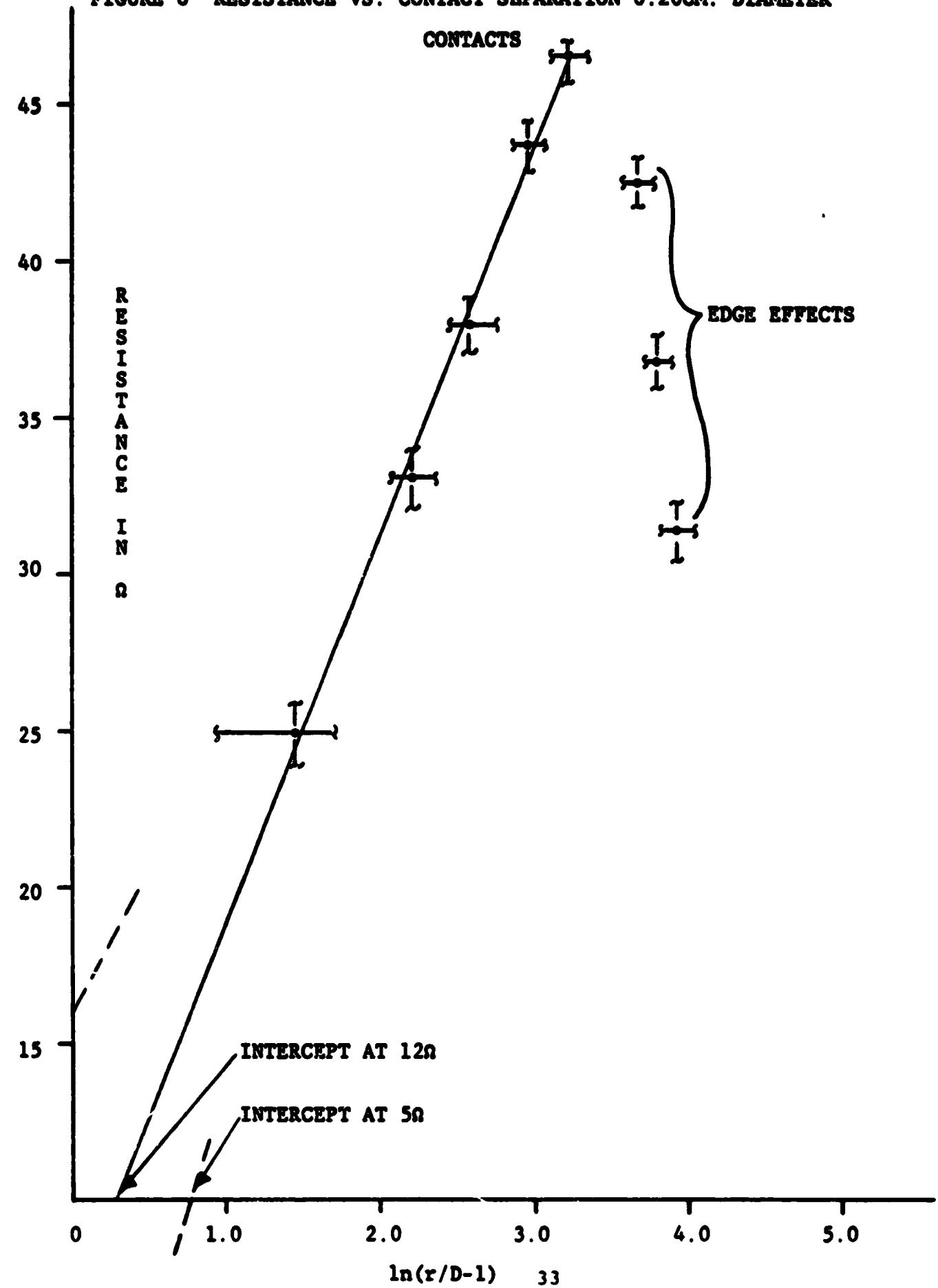


FIGURE 8 RESISTANCE VS. CONTACT SEPARATION 0.20CM. DIAMETER CONTACTS



The R_c value for the sample with linear grids is felt to be too large, possibly because of the long thin Ni grids used. Consequently, the resistance area product is too high. The other $R_c \cdot A$ products are felt to be reasonable even though they appear large at first sight, and yield an average of 0.26 ohm-cm^2.

To check these results, more samples were fabricated to evaluate the effects of contact size, solder dipping and sintering. Figure 9 shows the curve generated using 0.19 cm square contacts that have been Ni-plated and solder dipped. The value of 0.41 Ω-cm^2 agrees very well with the results reported last month. Sintering at 225°C for five minutes did not affect the results in the linear portion of the curve.

Figure 10 shows the curve generated using 0.292 cm sq contacts that have been Ni-plated and solder dipped. The results are consistent with the previous results.

These values are high, indicating a contact resistance contribution of approximately 0.026 Ω for a 10 cm x 10 cm cell. Literature values for contact resistance on solar cells indicate values between $1 \cdot 10^{-3}$ Ω-cm^2 and $1 \cdot 10^{-5}$ Ω-cm^2 (2,3). Further work must be undertaken to evaluate our results, comparing them to other metallization systems and to other measurement techniques.

3.9 Edging

The use of a laser scriber as originally envisioned is now under serious reevaluation. Coupling the laser trenching with the negative screen printing results in a high likelihood of shorting the interconnect or of shunting the cell by laser scribing through the edge metallization. Four alternate approaches have been identified and are being evaluated.

1. Oxide Mask Edge: The concept is to protect the edge of the cell during diffusion and plating by applying an undoped oxide to the edge. A variety of such undoped oxide pastes have been ordered and experiments are planned to verify its feasibility in our process sequence.

2. Plasma Etch: By stacking the wafers, a large number could be edge etched in one machine. It would be used to remove the Ni and n^+ layer before solder dipping or wave soldering. A demonstration is planned at a manufacturer's facility.

3. Laser Scribe Through the Silicon: Rather than trench with the laser, it could be used to cut all the way through the silicon. Such a high intensity laser may damage the silicon, causing shunting, but a demonstration will be arranged to determine if this is a problem.

FIG. 9 RESISTANCE VERSUS CONTACT SEPERATION
FOR 0.19CM. SQUARE CONTACTS

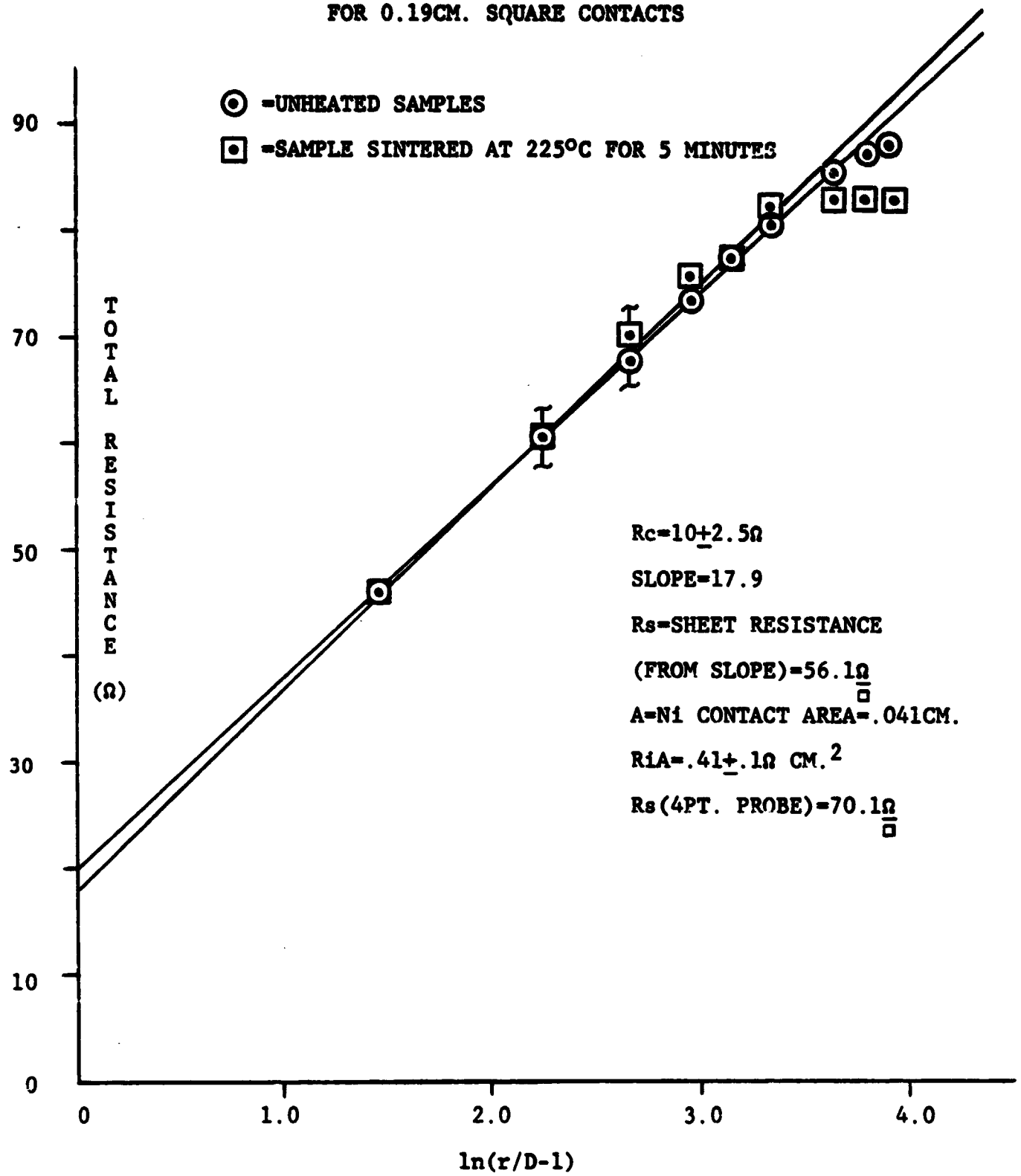
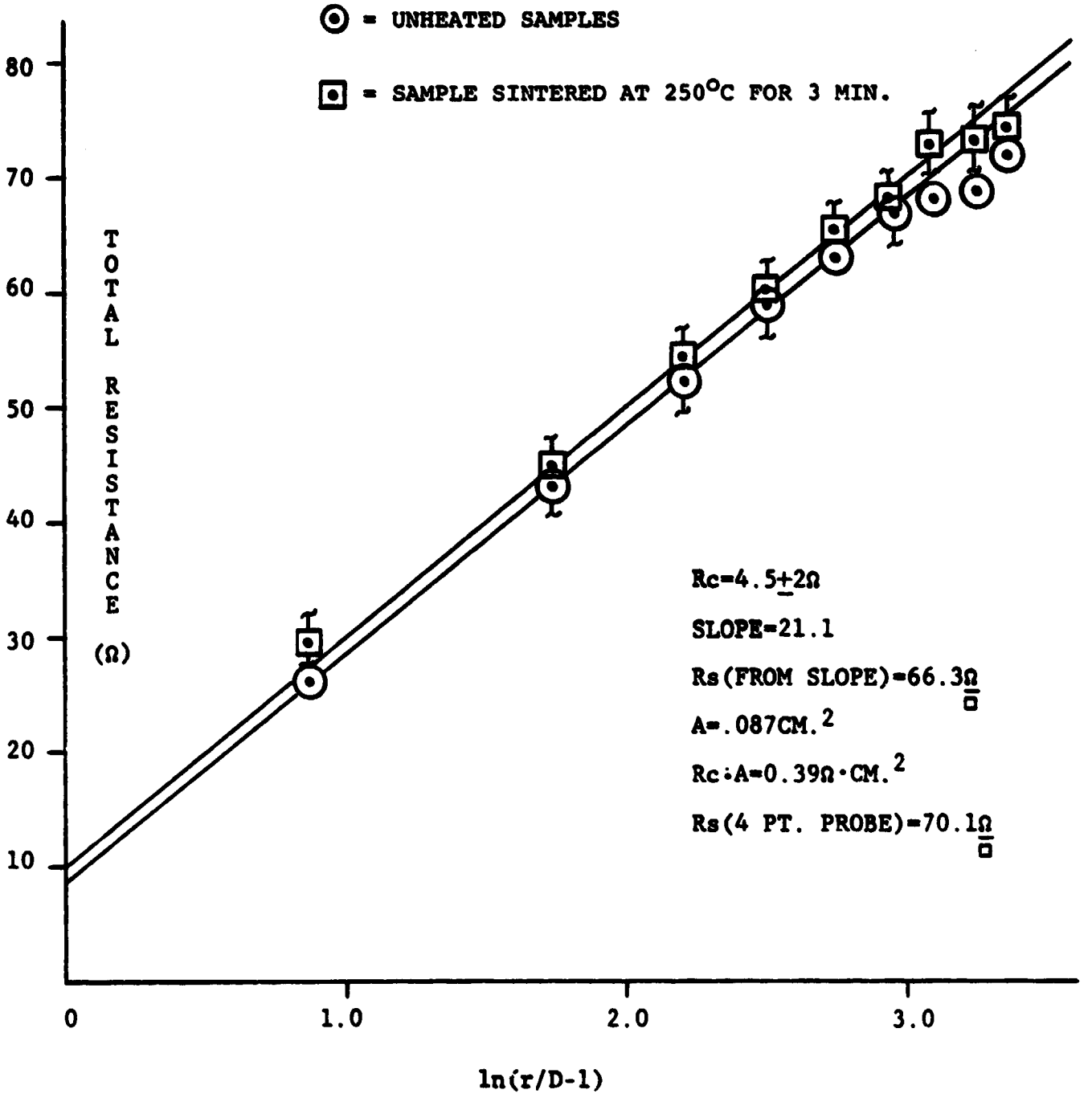


FIGURE 10 RESISTANCE VERSUS CONTACT SEPARATION

FOR 0.242CM. SQUARE CONTACTS



4. Screen Print All the Way to the Edge: The screen printer manufacturers have been asked to determine if a system can be set up that allows you to screenprint ink all the way to the edge of the wafer. If this works, then laser trenching is still a viable approach.

3.10 Preliminary Cell Fabrication

Preliminary cell fabrication has been initiated to provide cells for environmental testing. A preliminary laboratory process was defined and small lots consisting of 10 cm x 10 cm semicrystalline wafers and three inch single crystal controls were processed. The preliminary results are summarized below:

Isc	=	2.142	Amp
Voc	=	552	mV
Pmax	=	0.814	Watts
FF	=	0.69	
Eff	=	8.14	% (at AM1 and 25°C)
Yield	=	52	% (within 10% of average)

However, preliminary experiments indicate that, when encapsulated, these cells increase in current and power between ten and fifteen percent. This would result in cell efficiencies of approximately nine percent.

3.11 Tabbing and Stringing Machine

A request for quotation to build a tabbing and stringing machine was sent to a variety of vendors. Four quotations have

been received and discussions have been held with each to determine the appropriateness of their designs, their capabilities, and experience of their personnel, and the validity of the cost estimates. One of these proposals will be accepted during June.

Our interconnect material has finally reached the die maker. The plater had problems achieving a uniform solder thickness on such large sheets of copper. The material and tooling are now complete, so the first run will begin in early June.

Varo has presented us with a design for a bypass diode incorporated in the bus bar. A meeting was held discussing the design and revised drawings have now been resubmitted to Varo for a quotation.

3.12 Module Encapsulation

Comparison of Solarex's cure data with Springborn's indicated agreement on time-temperature cycles required for cure. The bubbling that Solarex sees at higher temperatures (150°C) was identified as gaseous reaction products that are forced out of the module by the higher pressures used by Springborn. Concern about the interrupted process resulting in a loss of curing agent has been satisfied by an analysis of Solarex's cure data as well as some experiments performed at Springborn. The result is that a 110°C lamination for 20 minutes does not reduce enough hyperoxide to cause a problem with the subsequent cure.

A number of insulator tapes have been identified that have passed our initial screening tests for adhesion to EVA and the cells and for electrical isolation. The tapes are given below:

Manufacturer	Film Carrier	Code No.
Polyken	Polyethylene	832
Permacel	Polyester	P280
Adhesive Research	Polyester	S5913
3M	Polyester, double coated	Y9769
3M	Polyester	480
Shuford	Polypropylene	PS 748

Each has shown promise with the Polyken 832, a polyethylene based tape, being a most likely candidate. Cost, availability, and ease of application will be used for best selection. They are all now undergoing environmental tests.

Preliminary efforts have been initiated in the lamination area to utilize air pressure rather than weights so that higher pressure (5 to 10 lbs/sq in rather than 0.1 lb/sq in) can be applied. This may provide better adhesion and allow us to use a higher cure temperature without suffering outgassing problems. The laminator was modified so that air could be slowly entered into the upper chamber above the diaphragm. Several full size modules (2 ft x 4 ft) were laminated without any cell breakage or bubbles in the EVA. The backs were very smooth and regular.

Modules (2 ft x 4 ft) with Ni-solder metallized cells have been fabricated and thermally cycled (-40 to +90) 50 times with no delamination or change in electrical performance.

The present RTV sealant used for gasket sealing offers several disadvantages, such as cost, and, although it is a satisfactory sealant for liquid water, it is not particularly effective toward water vapor and does not provide good adhesion to the glass or to the EPDM gasket. Taking a lead from JPL/ Springborn, initial experiments using a butyl hot melt HM-1081-A, an H. B. Fuller product, demonstrated excellent adhesion to glass. Its effect on the EPDM gasket needs to be determined and experiments are in progress.

The shrinkage of five polyethylene films at two temperatures are shown in Table 1. The shrinkage test temperatures were 110°C and 125°C in the temperature range which will cover the melting transitions of polyethylene. It should be noted that these temperatures are somewhat below the nominal temperatures used in laminating and curing and, therefore, during processing, the shrinkage forces are released. These tests indicated that all polyethylene films have free shrinkage at 125°C in excess of fifty percent.

Several full size panels were made with the Northern Petrochemical (NPE 190) slot extruded polyethylene. While the backs did not show massive shrinkage and, in fact, showed

Table 1. Shrink Results of Free Films* of Polyethylene Using Oil Baths as per ASTM D-2732-70 as Determined by Northern Petrochemical, Morris, Illinois.

Set Temperature	Percent Shrinkage			
	115°C		125°C	
Films	Machine Direction	Transverse Direction	Machine Direction	Transverse Direction
Northern Petrochemical (NPE 190) 6 mil, black resin	72	19	77	18
Rex Plastic (LLPDE) 5 mil, clear	10	2	69	14
Andmar (LDPE) 6 mil, black	60	6	61	3
Rex (LDPE) 6 mil, black	60	11	65	14
USI LDPE, 6 mil, black (NA 140 resin)	62	30	59	38

*The films were 10 $cm.^2$ and the percent shrinkage was determined in the machine direction and the transverse direction at two temperatures.

very little shrinkage, the results of the built-in thermodynamic instability plus lack of "hot modulus strength", i.e. tensile strength and elongation was apparent. The backs in the center portion had sequential cell shaped smooth spots separated by dished out spots, suggesting regions of concentrated stretch at divisional positions. The edges also developed pock marked spots with some lack of continuities in the polyethylene, suggesting excessive temperatures at the edges.

The ARCO black polyethylene Dylan 1909W is a low density polyethylene which is described as CATV power cable material. ARCO Polymers has blow molded a stubb roll for our testing. The 13 inch diameter tube has a blowup ratio of 2:1.

Several large panels were made using this back, each treated with somewhat different heating and pressure parameters. Some improvement over the previous panels was observed; the edge discontinuities were minimized. However, the back again showed the sequential smooth and dished out places. With additional work, cosmetic improvement is possible.

While the results with polyethylene backs were positive, a good deal of additional work is needed to achieve a cosmetically acceptable back. For example, a crosslinked polyethylene will have a better "hot modulus" and may be a better product. Crosslinked polyethylene film is available from Grace and samples are being obtained.

4.0 Recommendations and Schedule

The following technical questions must still be answered:

- To develop an edging technique that assures that the wraparound contacts will not short on the top edge of the cell;
- To get our wave solder machine operational to make cells using the entire proposed process sequence;
- To optimize all the processes for maximum cell performance; and
- To finalize a contract to get the tabbing and stringing machine built.

The following efforts will be undertaken during the next program period:

- Fabrication of cells for environmental testing of cells and modules;
- Determination of the optimum belt diffusion parameters;
- Evaluation of Ni plating as a function of sheet resistance;
- Continued development of the air pressure lamination procedure;

- Fabrication of preliminary MEPSDU modules;
- Environmental testing of cells and modules;
- Identification, discussions, demonstrations, and visits with potential equipment suppliers;
- Selection of a tabbing and stringing machine supplier and initiation of a contract; and
- Collecting of data for preliminary Samics analyses.

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3. Bernd Ross Associates, Development of Economical Improved Thick Film Solar Cell Contact, December 1979, Jet Propulsion Laboratory Contract No. 955164.